Small - Scale Morphology And Boundary Layer Processes: Measurement And Modeling

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Award Number: N00014-97-1-0790
http://www.diam.unige.it/ and http://hydr.ct.tudelft.nl/wbk/public/sedmoc/

LONG-TERM GOALS

The primary goal of the research project is to contribute to a better understanding of the basic mechanisms controlling sediment transport in the nearshore regions. In particular, the structure of flow in the bottom boundary layer is studied along with its interaction with sediment dynamics and bottom morphology. Attention is also devoted to the steady streamings generated both within the bottom boundary layer and throughout the water column up to the free surface.

OBJECTIVES

The dynamics of the coherent vortex structures are being studied which are generated by waves at the bottom by 1) the instability of the laminar boundary layer and the development of turbulence, 2) the nonlinear interaction of the oscillatory boundary layer with a wavy bed of small amplitude and with a sloping bottom, and 3) the separation of the boundary layer at the crests of 2-D ripples of large amplitude. Moreover, we want to investigate the steady streaming induced both close to the sea bed and far from it. The resulting velocity fields are used to study sediment dynamics and the processes, which lead to the formation of small and medium scale bedforms.

APPROACH

The investigation is based on analytical approaches, numerical simulations of momentum (Navier-Stokes) and continuity equations and the analysis of field data. Analytical solutions describing the flow field generated by a propagating wave close to the sea bottom are obtained to interpret selected field measurements and to study how the flow in the bottom boundary layer affects small and large scale morphodynamic phenomena. The numerical codes consider the full 3-D problem and simulate coherent vortex structures and turbulence. Field data are used to test the analytical results and the numerical findings.

WORK COMPLETED

a) A numerical code for the simulation of Navier-Stokes equations (developed in the framework of the project) has been used to study the separated oscillatory flow close to a rippled sea bed

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Small - Scale Morphology And Boundary Layer Processes: Measurement And Modeling**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Genova,Hydraulic Institute,Via Montallegro 1,16145 Genova - Italy,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

and to obtain results for relevant values of the parameters of the problem. Then the flow field has been employed to investigate sediment dynamics by a Lagrangian approach.

b) The study of the steady flow generated by a progressive wave propagating on a sloping beach has been completed. The steady velocity field has been determined both in the bottom boundary layer and in the core region for small and large values of the ratio between the wave amplitude and thickness of the bottom boundary layer.

c) An analysis has been carried out to investigate whether an appropriate rotation of the coordinate system exists such that the cross-correlation of the velocity components due to waves vanishes allowing the time average of the product of the remaining velocity components to provide estimates of the turbulent Reynold stresses.

d) The cooperation between the Naval Postgraduate School and Genoa University has been continued and in particular Prof. Blondeaux and Dr. Vittori have visited N.P.S. for about one month (June-July, 1999) and Dr. Scandura has visited N.P.S. for about three months (June-August, 1999).

The personnel exchanges from the beginning of the project can be summarized as follows:

Person/Position	from/to		Period
Dr. Foti Senior Research	Univ. of Catania (I)	Naval Postgraduate School (USA)	15 Aug. 97-15 Jan. 98
Dr. Vittori Senior Research Temporary Professor	Univ. of Genova (I)	Naval Postgraduate School (USA)	1 July 98-30 Aug. 98
Prof. Blondeaux Full Professor	Univ. of Genova (I)	Naval Postgraduate School (USA)	1 July 98-30 Aug. 98
Dr. Vittori Senior Research Temporary Professor	Univ. of Genova (I)	Naval Postgraduate School (USA)	15 June 99-15 July 99
Prof. Blondeaux Full Professor	Univ. of Genova (I)	Naval Postgraduate School (USA)	15 June 99-15 July 99
Dr. P. Scandura Post Doc.	Univ. of Genova (I)	Naval Postgraduate School (USA)	1 June 99-30 Aug. 99

RESULTS

(a) Sediment dynamics induced by an oscillatory flow over a rippled bed has been studied using a Lagrangian approach. The full 3-D Navier-Stokes equations have been employed to simulate the flow which is characterized by boundary layer separation at ripple crests and the generation of coherent 3-D vortex structures. To study sediment dynamics, it has been assumed that particle concentration is low enough to allow the use of a one-way coupling, i.e. the fluid moves the particles but there is no feedback from the particles to the fluid motion. Sediment trajectories have been used to gain information on particle dispersion due to the 3-D vortex structures, which characterize the flow field. Since experimental observations of oscillatory flow over a rippled bed show that sediment particles leave the bottom mainly at ripple crests, a first set of runs have been performed releasing sediments just above ripple crests. Sediment

distributions projected in a vertical plane are shown in figure 1 at different times for a particular set of the parameters. Sediment release starts at t=0 when the irrotational velocity far from the bottom is zero. However it is worth pointing out that the flow has been simulated for a long period before t=0 in such a way that the vorticity field at t=0 has attained a regime configuration. From figure 1 and the results of Blondeaux et al. (1999) describing the time development of the velocity and vorticity fields, it appears that during the accelerating phase the combined action of the attached boundary layer along the stoss side of the ripple and the clockwise vortex structure generated by flow separation at the ripple crest creates a small cloud of sediments just above the lee side of the ripple. Then the clockwise vortex structure couples with counter-clockwise vorticity generated during the previous cycle and forms a vortex pair which moves because of its self-induced velocity. A large amount of particles is captured by the vortex and is convected by it along the ripple trough. In the meanwhile, further clockwise vorticity is shed at the ripple crest and generates a new large vortex structure. Then the flow reverses and sediments are carried into suspension far from the bottom leaving the ripple profile at the crest, being trapped by the main vortex structure which is convected by the local velocity. However, some particles, because of their inertia, are flung out by the vortex structure and move in the streamwise direction reaching the trough of the adjacent ripple. Later on the main vortex structure couples with a new vortex of opposite sign which is shed at ripple crest and forms a vortex pair. The vortex pair moves because of its self-induced velocity which is superposed on the free stream velocity. In the meanwhile, further counter-clockwise vorticity is shed at ripple crest giving rise to a further structure, similar to that generated at the beginning of the simulation, which captures other sediments. Hence, after half the wave period and close to ripple crest, the flow and sediment concentration are the mirror images of those displayed at the beginning of the simulation, even though now a large cloud of sediments is present which leaves the bottom. This cloud of sediment is trapped by the vortex pair previously described. By continuing the simulation, it can be observed that viscous effects induce the decay of the vortex pair and that after few cycles gravity prevails over convective effects and sediment particles are released along the bed profile. It is interesting to point out that, even though sediment particles are released only from one crest, sediment distribution over adjacent ripples are similar, though weaker, thus showing that sediment dynamics is not largely affected by the location of particle release. Indeed repeating the simulation, but releasing the particles closer to the ripple crest, sediment distribution is equal to that shown in figure 1. Sediment dynamics is qualitatively similar in every vertical plane. However quantitative differences are present, which are induced by the 3-D character of the flow field. The large effect which 3-D coherent vortex structures have on particle dispersion can be appreciated following the trajectories of particles released at a fixed time. In the present model, particles that initially have the same x and y but different values of z tend to form elongated patterns characterized by a mushroom shape.

(b) The shoaling process of a wave propagating on a gently sloping beach and partially reflected at the coast has been investigated with particular emphasis on modeling the vertical structure of the wave induced mass transport which takes place outside the surf zone. The wave induced steady streamings seaward of the breaking region have been evaluated under the assumptions of shallow waters. In order to validate the model, in which we have assumed that the flow within the bottom boundary is laminar, experimental data, in which the near-bed turbulence intensity offshore of the breaking region is as low as possible, should be considered. To this purpose a good data set seems to be that of Hwung & Lin (1990) in which a number of mass transport profiles, collected outside the surf zone, are reported. Four types of monochromatic waves have been studied which led to both plunging (Test 1, 2 and 3) and spilling (Test 4) breaking. Validation has been performed by using data relative to Test 1 (plunging breaking)

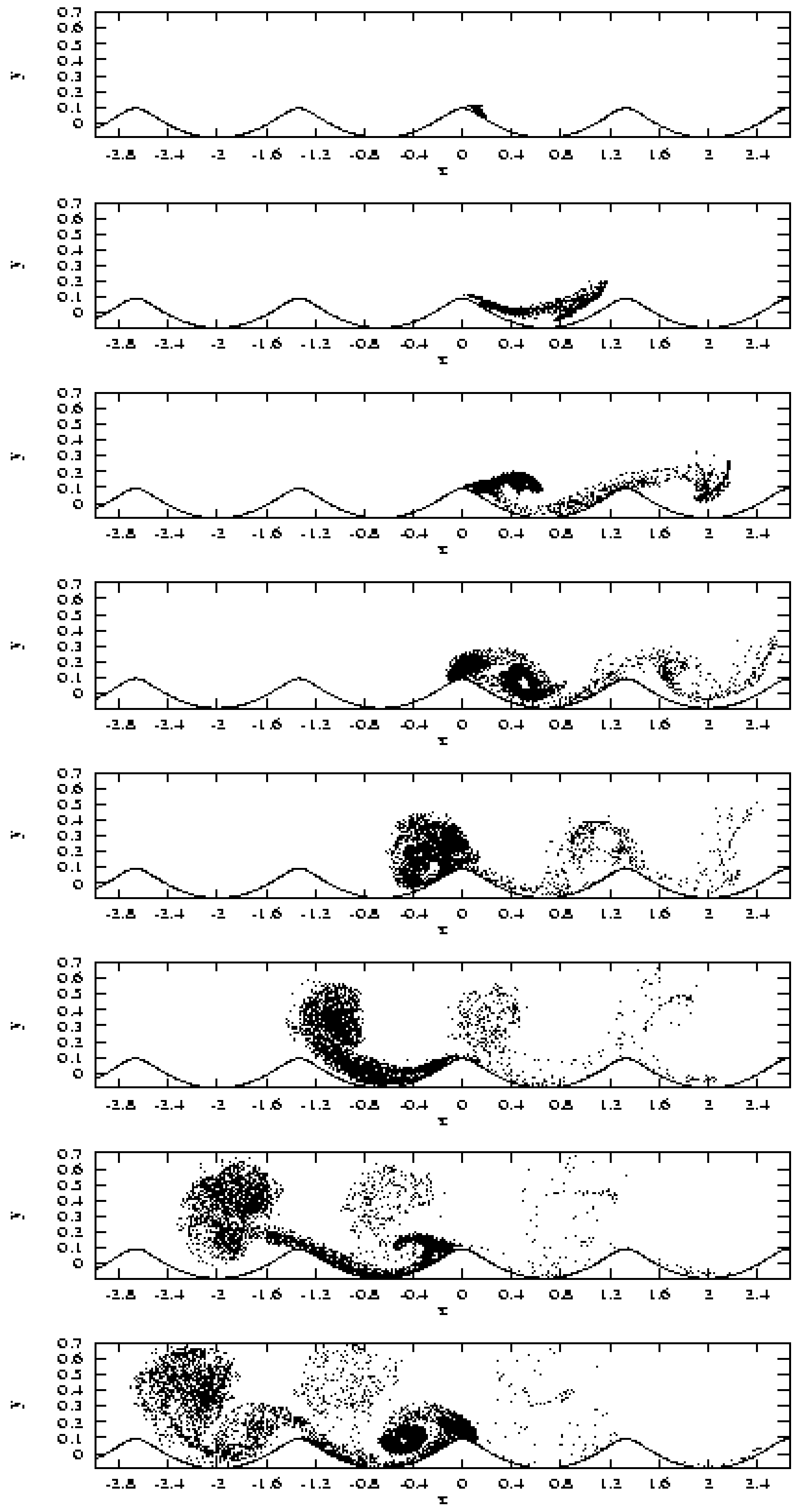

Figure 1: sediment distributions projected into a vertical plane at different phases of the cycle

and Test 4 (spilling breaking). The comparisons are summarized in figure 2. The model well represents the mass transport independently of the type of breaking (plunging or spilling)

undergone by the incident waves. Some discrepancies, however, can be found when considering data relative to the most inshore gauges. It is evident that different behavior

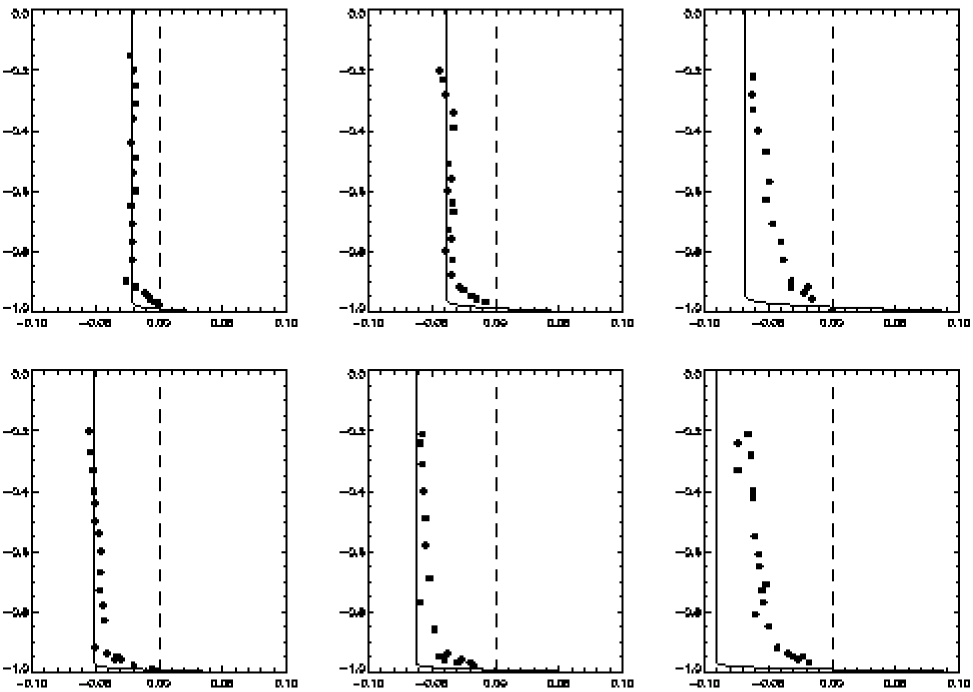

Figure 2: comparison between theoretical predictions and experimental data of the steady velocity component under sea waves (top row-test1: P3, P6, P9; bottom row-test4: P3, P4, P6).

characterizes the experimental data relative to the most inshore gauges (P_9 for Test 1 and P_6 for Test 4) compared to those collected farthest offshore. The latter represent a very uniform distribution over the vertical while the former are characterized by a gradually increasing velocity from the bottom up to the still water level. We argued that this is caused by the strong vertical flow mixing induced by the presence of turbulence, which is produced by the wave breaking and convected seaward of the breaker line by steady streamings. Hence a new model has been formulated to describe the undertow structure offshore of the breaker line by assuming the flow regime in the bottom boundary layer to be turbulent. The turbulence field generated by wave breaking has been taken into account too. The results of the new model well agree with field data collected by N.P.S. group.

(c) The velocity field induced by a sea wave propagating on a sloping bottom has been determined to evaluate the cross-correlation of the velocity components away from the bed. Waves of small amplitude propagating in shallow water have been considered, but the results are felt to provide useful information also for finite depths and large amplitude waves. The analysis has been carried out to investigate whether an appropriate rotation of the coordinate system exists such that the cross-correlation of the velocity components due to waves vanishes allowing the time average of the product of the remaining velocity components to provide estimates of the turbulent Reynolds stresses. The obtained results show that turbulent Reynolds stresses can be evaluated from field measurements of velocity components, if an appropriate reference frame is chosen rotated with respect to the gravity oriented reference system. The tilting angle depends on the bottom profile and on the characteristics of the wavefield. As suggested by Stanton & Thornton (1996) the angle can be computed by minimizing the measured covariance between horizontal and vertical velocity components. However the present analysis suggests that the procedure should consider different wave components separately and should

be applied sequentially at different heights from the bottom. A preliminary analysis of the field data seems to suggest the validity of the theoretical results.

IMPACT/APPLICATIONS

RELATED PROJECTS

“Sediment Transport Modeling in Marine Coastal Environments” research project of European Union. MAS 3-CT97-0115 "Sedmoc".

“Nearshore Wave and Sediment Process”, Office of Naval Research.

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PUBLICATIONS

(List of papers acknowledging the support of NICOP Project)

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